STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

Progress Report

on

STUDIES ON THE CAUSES AND PREVENTION OF ERRATIC CRACKING IN CONCRETE PAVEMENTS

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November 1, 1961

MATERIALS & RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways

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Work Order No. 60-13NN14
Lab. Auth. No. 5039-S-55

Mr. L. R. Gillis
Assistant State Highway Engineer
Division of Highways
Sacramento, California

Dear Mr. Gillis:

Submitted for your consideration, is a progress report on:

Studies of the Causes and Prevention

of Erratic Cracking in Concrete Pavements

Study made by . . . . Technical Section
Under direction of . . . . Bailey Tremper
Work Supervised by . . . . D. L. Spellman
Report prepared by . . . . Bailey Tremper and D. L. Spellman

Very truly yours

F. N. Hveem
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PROGRESS REPORT
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STUDIES ON THE CAUSES AND PREVENTION
OF ERRATIC CRACKING IN CONCRETE PAVEMENTS

WO 60-13NN14 - Lab Authorization 5039 S 55

Introduction

This investigation is being conducted in accordance with verbal instructions from Mr. J. W. Trask, Assistant State Highway Engineer, Operations, in August, 1959. The investigation is financed in part with Federal funds. For the purpose of this study, "erratic" cracking is defined as deep seated cracking having no pronounced orientation with respect to the margins of the pavement. The areas enclosed by the cracks, and/or the pavement margin usually being from about 10 to 75 square feet. For convenience in discussion, erratic cracking is designated as Type 2. See Figure 1.

Preliminary investigations suggested that erratic cracking occurred in pavements in which the upper portion was considerably more absorptive than the lower portion. Part I of the over-all study was, therefore, planned to learn if such a conclusion could be substantiated. The major portion of this report is concerned with findings under Part I. Part II of the investigation deals with field observations during current construction to determine if erratic cracking is related to certain atmospheric conditions or construction practices. This part of the investigation was started only recently and no conclusions can be reached at this time, but the subject is discussed in the latter part of this report.

PART I

Part I, then, deals with differences in absorption of top and bottom portions of pavements as determined by absorption tests of pavement cores sawed in two at mid-depth. The relationship between absorption differences and the occurrence of erratic cracking is discussed.

Available information on absorption differences was fragmentary. To secure better information on this factor from past construction on a statewide basis, cores were obtained from 22 projects which comprised pavements constructed over a 12-year period. The projects were in different parts of the state and were constructed by different contractors, presumably with somewhat different equipment. In addition, all known pavements in which erratic cracking was known to have occurred, were cored and tested, not only in the areas in which cracking had occurred, but also in areas free from such cracking. At the time jobs for coring were selected, there were six in number having erratic cracking. They comprised of two projects in each of Districts III, IV and VI, all of which were constructed during the period 1956 to 1959. The projects studied are listed in Table 1.

Most of the pavements contain cracking of some type. The different types are broadly classified and illustrated in Figure 1, and the occurrence of the type of cracking found in each pavement is shown in Table 1.

Test Methods

Cores were 5 inches in diameter and were secured with diamond bits. Upon receipt in the laboratory, the cores were sawed in two at mid-depth. They were then immersed in water for periods of from two to three days and were then weighed and dried in an oven at 220° to 230°F. Percentage of absorption is reported as 100 times the loss in weight during oven drying divided by the oven dry weight of the specimen. Values of absorption of the whole core were calculated as the average of the core halves.

Results of Tests

Results of absorption tests on cores from the six pavements in which erratic cracking was found are given in Table 2. A separation is made between cores from cracked and uncracked areas.

Results of absorption tests on cores from the 22 pavements in which no erratic cracking was found are given in Table 3. A separation is made between areas having no cracking and those having cracking of types other than Type 2, or "erratic" cracking.

Discussion of Test Results

Variations in absorption of cores from area to area in concrete having the same aggregates and cement factor, could be caused by either a variable water-cement ratio when mixed, lack of consolidation when placing, or variation in the amount of entrained air, which could possibly be caused by a difference in the amount of air being entrained in concrete coming from two mixers, or by malfunction of the air-entraining agent injector. Voids caused by lack of consolidation are usually large and easy to see. The appearance of the cored faces of cores from cracked and uncracked areas was not noticeably different.

It is, therefore, more likely that the differences in absorption between whole cores were mostly the result of varying water content in the concrete when it was mixed. Differences in absorption between projects in which different aggregates were used may have been affected by the absorption of the aggregates.

On one job, Contract 57-4TC45, it was found that the concrete varied in absorption because of an excessive amount of entrained air caused by a faulty dispenser, in certain parts of the work. Erratic cracking was found in areas containing excessive amounts of air, but it also occurred elsewhere. Cores from areas of excessive air content have been excluded in the data in this report.

Laboratory made concrete which was cored after hardening indicated that uniform concrete, as mixed and placed, has very little difference in absorption between the top and bottom halves. Two lab mixes were tested; one having 3% entrained air and the other having 10% entrained air.

While the job cores from the cracked areas taken as a whole had substantially the same average differences as did cores from uncracked areas, the individual cores had differences that were quite large; sometimes the top half having the highest absorption, sometimes the lower half. The concrete was more erratic in this respect. A number of things can cause the differences observed. Accelerated drying and hardening of the concrete could cause the bottom half to be denser if the hardening occurred before all bleeding was finished. Excessive working of high slump concrete causes mortar to be brought to the surface. The absorption of the mortar is significantly greater than absorption of concrete as a whole, and would cause the top portion of the slab to have higher absorption. The appearance of cores from cracked and uncracked areas did not indicate any difference in the amount of mortar in the top halves of the cores.

Referring to Table 2, it will be seen that the range in absorption differences of cores from cracked areas, is from -0.37 percent to +1.15 percent, the results being positive (higher absorption in the top half) in all but one project. The absorption differences of cores from uncracked areas is from +0.39 percent to +0.78 percent. It does not appear from this data that the occurrence or non-occurrence of erratic cracking is related to differential absorption; that is, to a difference in porosity of the top and bottom layers. It will be noted also that absorption values of whole cores, with one exception, are higher in cracked than in uncracked areas. The average excess in absorption for five of the six projects, is 0.20 percent in the cracked areas which indicates that the cracked concrete contained somewhat more water which may have resulted from higher slumps, finer aggregates, or possibly, poorer curing.

Therefore, the indications of absorption tests of cores from the pavements exhibiting erratic cracking, are that such cracking is more likely to occur in concrete of higher water content, or possibly in pavement that has been inadequately cured. By inadequate, it is meant that curing methods employed may have failed to meet the requirements during adverse conditions. Such a conclusion should not be reached without reservation however, without inquiring into absorption values of pavements that are entirely free from erratic cracking.

Referring to Table 3, it will be seen that the variation in absorption in the uncracked areas is from -0.50 percent to +0.87 percent, which range is comparable in order of magnitude to that found in areas of erratic cracking in other pavements. There is no pronounced trend in absorption differences of those areas in this group in which some type of cracking has occurred compared to areas that are free from cracking. In some cases, the differential is greater in the cracked areas; in other cases, the reverse is true. The average differential is virtually the same for cracked and uncracked areas. Considering the absorption values of the whole cores, it will be noted that the average value is 5.25 percent, which is considerably less than the average value of 6.12 percent found in the cracked areas of those pavements which developed erratic cracking. The difference in absorption is probably due to differences in absorption of aggregates, but it can hardly be concluded that absorptive aggregates are prone to develop erratic cracking because there are instances of high absorption in the group of uncracked pavements.

The general conclusion is that erratic cracking was not connected with differences in porosity of the upper and lower portions of the pavements. It is concluded that the causes of erratic cracking must be sought in other directions with which Part II of the investigation deals.

PART II

Other Factors Considered

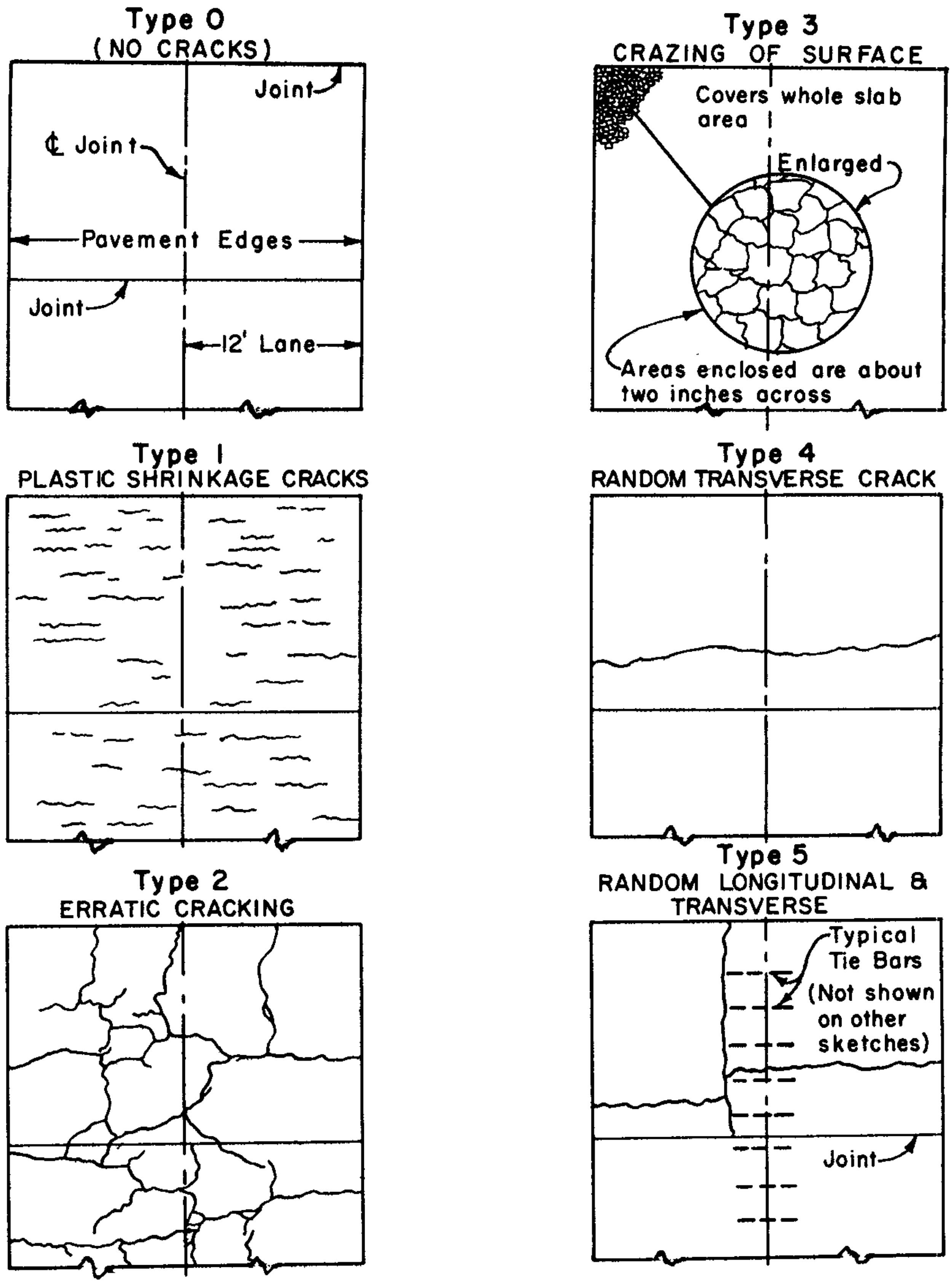
Some evidence that points to the causes of erratic cracking can be found by considering field conditions and noting where and when such cracking usually appeared. The cracking has not appeared in every day's placement. It most often occurred near the morning joint and proceeded from 200 to 800 feet into the day's work before gradually fading out. Two conditions that are often different in morning placement with respect to operations, are wetness of the concrete, and the fact that curing is delayed the longest on the portion of concrete placed first during the day. Concrete is often "wetted" up at the beginning of the day's run to facilitate hand finishing necessary near the joint. The water is reduced as the paving train moves ahead, but it sometimes goes several hundred feet before such adjustments are made. Curing is not started until later in the morning so that the concrete placed first is without curing the longest. On a hot day, the temperature of the concrete placed first gets higher than that placed later in the day. When it cools, it goes through a greater temperature change and hence a greater volume change. Large volume changes at early ages induces cracking as the concrete is not yet strong enough to resist the forces involved. The volume change due to drying plus the volume change due to temperature becomes critical sometime after placement. If curing is not adequate, considerable drying shrinkage can occur during the first few days after construction. Much of the erratic cracking of pavement has been observed within a few days after placement before any loads are placed on it, and seems to progress somewhat after opening to traffic indicating that cracking is present soon after placement but may not all be visible at first. Compressive strength tests on concrete cores several weeks old or older, show that from a strength standpoint, the concrete is about equal in both cracked and uncracked concrete. Curing studies show that differences in strength of concrete cured in different manners tends to disappear with age, but at early ages (a few days), such differences can be large.

Weather conditions obviously affect slab performance. Since weather is not the same from day to day, it could explain why cracking occurred on some day's work and not on others, even though all other conditions seemed the same. To secure information about actual weather conditions and other construction conditions, measurements of temperature, relative humidity and wind velocity have been made on three recently constructed pavements in the valley near Sacramento, and on one job in the mountains near Monte Vista on U.S. Interstate 80. The days on which the measurements were made were relatively warm, although not warmer than had been experienced earlier in the summer when no paving was in progress on these projects. In addition to taking the temperature of the air and concrete at regular intervals, an atmometer was employed which gives a measure of the rate of evaporation of water from the surface of a disk made of filter paper. Separate measurements of relative humidity and wind velocity were also made periodically, but it is believed that the evaporation rate, as measured by the atmometer, integrates the effects of temperature, wind velocity and relative humidity. Evaporation rates varied from 0 to a high of about 20 ml per hour. A few of the days during which measurements were made could well be considered adverse for placing concrete. A preliminary follow-up has been made on the three valley jobs which shows a much higher frequency of cracking in the portion of pavement placed in the morning than that placed after noon, although as yet there is no Type 2 cracking. The cracks are the random-transverse type extending across the pavement, generally at right angles to the center line. Most of them now serve as contraction joints.

It should be pointed out that curing procedures have changed slightly since Type 2 cracking became a problem. Information has been given to construction personnel on how to prevent severe cracking by providing fog spraying with water both before and after the curing seal is applied. The rate of application of the curing seal has been increased by specification to 150 square feet per gallon over the old rate of 200 square feet per gallon. Hooded sprays are now required to prevent loss of compound during windy weather. While some of these measures were employed on jobs placed during the last one or two years, they have not entirely eliminated cracking of types other than Type 2. On at least two jobs, sprinkling with water was employed to keep concrete temperatures down and while not all cracking was eliminated, it was greatly reduced. Temperatures of the concrete taken on one of the jobs indicated that the interval between application of the water was too great as the applied water soon evaporated and concrete temperatures continued to climb. No burlap or other covering was used to retain the water after it was applied.

Summary

The causes of Type 2, erratic, cracking have not as yet been fully and clearly determined. Other types of cracking continue to develop where weather conditions are adverse to concrete operations. Additional work is planned as a continuation of the study and includes more on-the-job observations and measurements of the type described. Some control sections on which curing conditions are varied would be desirable, but may result in more severe cracking than has been experienced on recent jobs. Records of on-the-job conditions will be valuable even if no cracking occurs as they will provide information about conditions under which pavements can be placed without cracking tendencies. Records are available on a very limited number of projects now. Laboratory personnel will be used to secure the information as construction personnel rarely have time to make the necessary measurements. The laboratory also has the equipment needed. The information obtained will be used as a guide for taking whatever action is found to be necessary to reduce cracking of all types once the basic causes are clearly documented.



GENERAL CLASSIFICATION OF CRACKING IN PCC PAVEMENTS

TABLE 1

Jobs Cored in Connection with Project 60-13NN14
Investigation of Causes of Erratic Cracking
in PC Concrete Pavements

Contract No.	Co. Rte. Sec.	Type of Cracking *
59-3TC3	III-Nev-38-A	2
59-3TC4	III-Nev-38-B	2
56-4TC35-F	IV-C.C-75	1,2,4,5
57-4TC45	IV-Ala-69-E	1,2
58-6VC14	VI-Ker-4-A,B	2
59-6VC18-FI	VI-Ker-4-B	2
60-3TC9	III-Yol-90-A,B	4
0-4TC73	IV-Nap-74-A	1
51-4TC86-F	IV-Ala-5-F	5
52-4TC27-F	IV-C.C-75	0
56-4TC4-F	IV-C.C-75-A	1,4
57-4TC11-F	IV-Son-1-C	1
52-5TC52-F	V-Mon-2-B	1
59-5VC6-F	V-SLO-2	1
1-6VC42	VI-Ker-4-C	0
57-6VC11	VI-Ker-4-B	3
58-6VC2	VI-Tul-10-B	0
51-7VC36-F	VII-L.A-4-LA	1
55-7VC44-F	VII-L.A-158-LA	0
57-7VC28-P	VII-L.A-2-LA	4
58-7VC7-F	VII-Ven-2-B	0
58-7VC16-FI	VII-Ora-2-A	3,4
58-7VC18-FIPD	VII-L.A-2-LA	0
54-8VC2-F	VIII-SBd-26-C	1,5
55-8VC25	VIII-Riv-26-Ban	4
56-10TC20-F	X-S.J-4-B	1
53-11VC1-F	XI-S.D-2-B	4
58-7VC25-FIP	VII-L.A-158-Clc	0

*See Figure 1

TABLE 2

Absorption data of Pavements having Erratic Cracking

Contract No.	Type 2 Cracked Areas				Uncracked Areas			
	Average Absorption of			Top Minus Bottom	Average Absorption of			Top Minus Bottom
	Top Halves	Bottom Halves	Whole Core		Top Halves	Bottom Halves	Whole Core	
59-3TC4	6.41	5.93	6.17	0.48	6.58	6.19	6.39	0.39
59-3TC3	7.88	7.48	7.68	0.40	7.63	7.08	7.36	0.55
56-4TC35-F	5.76	5.22	5.49	0.54	5.50	4.93	5.22	0.59
57-4TC45	5.86	4.71	5.29	1.15	5.57	4.79	5.18	0.78
58-6VC14-FI	5.68	6.05	5.87	-0.37	*			
59-6VC18-FI	5.98	5.95	5.97	0.03	5.67	5.18	5.43	0.49
Average *	6.38	5.86	6.12	0.52	6.19	5.63	5.92	0.56
Total No. of Cores			98				49	

*No cores from uncracked area on this contract - not included in averages shown for cracked or uncracked areas.

TABLE 3

Absorption data of Pavements free from Erratic Cracking

Contract No.	Cracked Areas other than Type 2: Average Absorption of Top Halves	Bottom Halves	Whole Core	Top Minus Bottom	No. of Cores	Uncracked Areas: Average Absorption of Top Halves	Bottom Halves	Whole Core	Top Minus Bottom	No. of Cores
60-3TC9						6.07	6.10	6.08	-0.03	19
0-4TC73	4.80	4.54	4.67	0.26	8	4.65	4.48	4.57	0.17	4
51-4TC86-F						4.68	4.54	4.61	0.14	12
52-4TC27-F	5.15	5.18	5.16	-0.03	4	5.35	4.96	5.16	0.39	8
56-4TC4						5.13	4.71	4.92	0.41	7
57-4TC11-F	5.78	5.74	5.76	0.04	1	5.99	5.90	5.95	0.09	11
52-5TC52-F	4.45	4.35	4.40	0.10	4	4.43	4.40	4.42	0.03	8
59-5VC6-F	5.88	5.73	5.81	0.15	4	6.39	5.93	6.16	0.46	8
1-6VC42						5.95	5.95	5.95	0.0	12
57-6VC11						5.48	5.05	5.27	0.43	12
58-6VC2						5.46	4.59	5.03	0.87	12
51-7VC36-F	5.00	4.53	4.77	0.47	4	4.70	4.85	4.78	-0.15	8
55-7VC44-F						5.44	5.69	5.56	-0.26	8
57-7VC28-P						5.38	5.09	5.24	0.29	12
58-7VC7-F						5.21	5.31	5.26	-0.10	12
58-7VC16-FI						5.28	5.19	5.24	0.09	12
58-7VC18-FIPD						5.74	5.37	5.56	0.37	12
54-8VC2-F	5.20	5.23	5.21	-0.03	4	5.18	5.36	5.27	-0.18	8
55-8VC25						4.65	4.71	4.68	0.06	12
56-10TC20-F	5.65	5.98	5.82	-0.33	4	5.71	6.21	5.96	-0.50	8
53-11VC1-F						5.19	5.38	5.29	-0.19	12
58-7VC25-FIP						4.81	4.26	4.54	0.55	12
Averages	5.24	5.16	5.20	0.08	33	5.31	5.18	5.25	0.13	229